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F. Garcia, J. W. Forbes, C. M. Tarver, P. A. Urtiew, D. W. Greenwood, K. S. Vandersall

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PRESSURE WAVE MEASUREMENTS FROM THERMAL COOK-OFF OF AN HMX BASED HIGH EXPLOSIVE PBX 9501

Frank Garcia, Jerry W. Forbes, Craig M. Tarver, Paul A. Urtiew, Daniel W. Greenwood, and Kevin S. Vandersall

Lawrence Livermore National Laboratory, 7000 East Avenue L-282, Livermore, CA 94550

Abstract. A better understanding of thermal cook-off is important for safe handling and storing explosive devices. A number of safety issues exist about what occurs when a cased explosive thermally cooks off. For example, violence of the events as a function of confinement are important for predictions of collateral damage. This paper demonstrates how adjacent materials can be gauged to measure the resulting pressure wave and how this wave propagates in this adjacent material. The output pulse from the thermal cook-off explosive containing fixture is of obvious interest for assessing many scenarios.

INTRODUCTION

The effects of the HMX $\beta \rightarrow \delta$ phase transition, [1-3] which at atmospheric pressure occurs near 160°C, on thermal ignition, impact sensitivity and the kinetics of the cook-off processes need to be better understood for HMX containing explosives. Questions exist on the level of violence of these events as a function of confinement and thermal heating rates. In addition, the acceleration of the metal case by this type of thermal reaction is needed to access whether the resulting flyer can initiate detonation or reaction in a neighboring explosive item. Thus, results of cook-off events of known size, confinement, and thermal history are essential for developing and/or calibrating reactive flow computer models for calculating events that are difficult to measure experimentally.

EXPERIMENTAL PROCEDURES

Three different experiments on thermal exploding explosives have been performed. Two experiments thermally exploded stainless steel encased PBX 9501 (HMX/Estane/BDNPA-F; 95/2.5/3.5 wt %) donor charges. A transmitted two-dimensional pressure wave was measured by gauges in cylinders of Teflon or PBX 9501 that were in contact with the donor. A third experiment measured the thermal distribution in a Teflon system using the same metal fixture and the same heating rates used in the explosive donor experiments. A fourth experiment is currently assembled and awaiting testing.

In all experiments except TEXT V, the PBX 9501 cylindrical disc is confined by 304 Stainless Steel. The HE disc and case was designed such that the explosive would come into contact with all surfaces when the explosive was near 150°C. Some imprecision existed on when the HE came into contact, because the HE was not uniformly heated as the thermal expansion calculation assumed. The front 12.4 mm thick stainless steel plate was fastened to the 12.4 mm rear steel plate with several grade A hardened steel bolts tightened to 70 ft-lbs. Each 9.0 cm by 2.5 cm thick disk of PBX 9501 weighing 295 g was radially contained by close fitting stainless steel ring with wall thickness of 34.5 mm. The ring height was the same as the explosive disc. A 3 mm thick 6061 T6 aluminum plate was placed between the front steel plate and the explosive to distribute the heat faster and more uniformly and also served as a gasket for a compression seal since both steel interfaces had knife edges machined in them.

A flat spiral ribbon heater made of nichrome foil was placed between the steel cover plate and the aluminum plate. Two thermocouples monitor the temperature and control the heating rate of the heater. No thermocouples were placed internal to the steel encased PBX 9501 to allow for a simple pressure seal design for the steel fixture. The same heater configuration was also placed at the back of the target assembly.

The triggering of the power supplies and the digitizers is a critical feature of this experiment. For the primary triggering system and to measure the wave arrival at the bottom steel plate surface, a series of thirteen PZT pins in a cross pattern with one pin at the center and each pin being 15 mm center to center distance apart were placed against the bottom steel plate. A back-up break wire trigger system was used to provide a trigger pulse from a circuit if any of the wires broke. These thirteen PZT pins and break wires were all summed so the first signal generated would trigger the digitizers and power supplies to allow collection of the data.

Carbon resistor gauges have been used successfully in two-dimensional shock wave experiments where time resolution was sacrificed for survival of the gauge [4-6]. The constant current power supply for the carbon resistor gauges is always on passing about 16 mA through the 470 ohm resistors. The constant current pulse power supply for the manganin gauges is the Dynasen CK2-50/0.050-300.

Manganin gauges have been successfully used in numerous one-dimensional strain experiments [7]. It has also been shown to be temperature insensitive [8]. Numerous papers in the literature have discussed the calibration of this gauge, but only a two are selected [9,10] here for reference.

Experiment TEXT V was a thermal simulation experiment with the Teflon discs inside the steel case replacing the PBX 9501 discs. Thermocouples were at a number of interfaces in this mock donor system. The same heating procedure of this inert donor system was done. The thermal traces are not reported here but can be used to calibrate a thermal code which can then provide the time and spatial history of the heated PBX 9501 donor. Recall that no thermocouples were used inside the donor explosives for these experiments.

Experiment TEXT VI is shown in Fig. 1. Both manganin and carbon resistor gauges were placed at different depths in the PBX 9501 cylinder acceptor. A 10 mm thick Teflon disc is placed between the steel top plate of the confined donor system and the acceptor to provide thermal insulation for the acceptor charge. This insures that the acceptor does not cook-off. A second benefit is to keep the temperature down on the carbon resistor gauges since they are temperature sensitive and no calibration exists for this gauge at temperature.

An experiment similar to TEXT VI, but with a Teflon acceptor was performed previously and is not included here for brevity. Details are provided elsewhere [11].

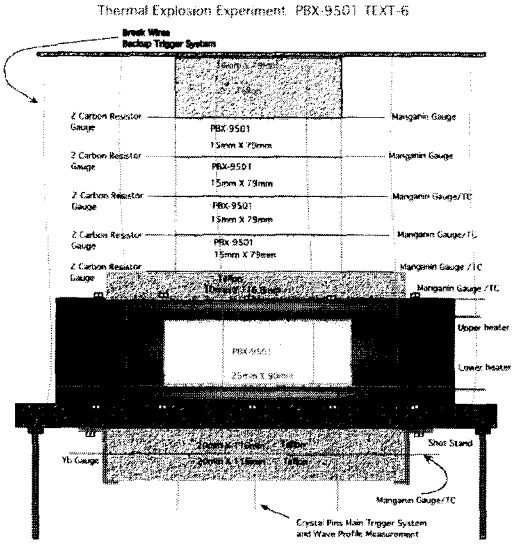

Figure 1. Schematic for TEXT VI thermal explosion experiment

RESULTS

Experiment TEXT VI

Fig. 2 gives the temperature time profiles for the five thermocouples that behaved well for TEXT VI. These show that rapid explosion occurred when the thermocouples at the metal surface of the donor system reached 209°C. The initial heating rate was 5.7°C per minute up to 170°C at the metal surface of the donor. Then the temperature at this surface was held at 170°C for 35 minutes to allow for the donor to be somewhat uniform in temperature. From the soak temperature of 170°C, the heating rate resumed at 1°C per minute until cookoff occurred. The temperatures in the acceptor did increase but at much lower rates and magnitudes. These temperatures were high enough that the carbon resistor gauge calibration will need to be done for this range of temperatures to improve the accuracy of these measurements.

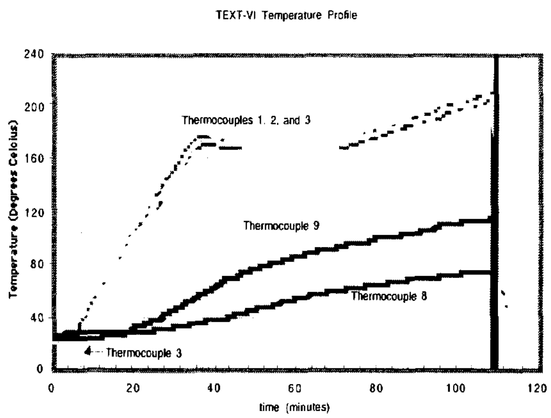

Figure 2. Temperature profiles of various thermocouples at various locations in the TEXT VI target

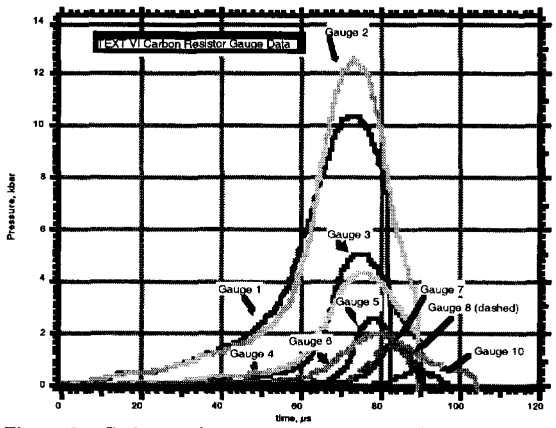

Figure 3. Carbon resistor pressure gauge results for TEXT VI.

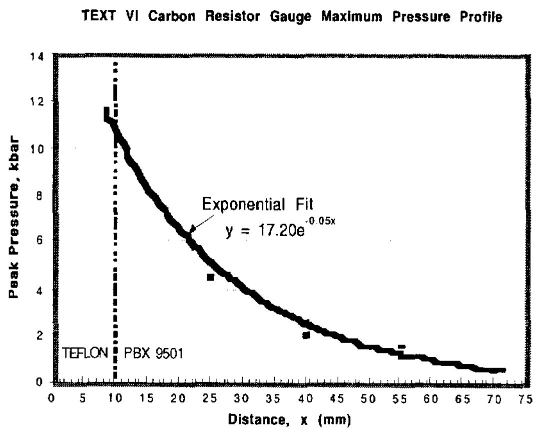

Figure 4. Peak pressures of the carbon resistor gauges as a function of Lagrange distance

The carbon resistor pressure gauge results (without temperature corrections) in Fig. 3 show that a ramp wave with peak pressure of 12 kb exists at the first gauge level in the acceptor. Some variation in gauge pressure exists for gauges on the same plane which is likely due to the ramp wave not being symmetric as it propagates into the acceptor. Variation between gauges is smaller than this observed difference of 2 kb at the first gauge station. The ramp pressure wave decays very rapidly as it moves up the acceptor charge and the rise time of the ramp shortens. This decay is faster than observed in the Teflon acceptor of TEXT IV consistent with PBX 9501 being a stiffer material with faster release wave speeds. It is clear that for TEXT VI the wave did not build into a detonation, which would be a more severe safety issue. The decay of the ramp wave peak pressure is given in Fig. 4. The peak pressure decay is fitted accurately to an exponential function.

The manganin foil gauge is sensitive to lateral strain. This makes this gauge mainly useful for one-dimensional strain experiments. For two-dimensional dynamic strain experiments, J. Charest [12] has shown that the gauge analysis can correct the signals for small strains. This requires the use of a strain gauge in the experiment at the same location (or very close) to the manganin gauge element. Since the ramp wave did not build into a high pressure wave or a detonation, the manganin records were not much above the noise level of the digitizers. These records are of limited value and therefore not reported here.

SUMMARY AND FUTURE WORK

A multi-dimensional ramp pressure wave is transmitted to the acceptor materials (Teflon or PBX 9501) from an explosive deflagration cook-off of a confined PBX 9501 donor system with a peak pressure of around 12 kb. This ramp wave's peak pressure decays rapidly while the rise time of the ramp decreases. These pressures are substantial and will scatter burning materials around significantly but for these experimental conditions build-up to detonation in the acceptor does not occur.

Future work on this area will include additional experiments with different heating rates and confinement. In addition, some future experiments will measure the velocity of the steel cover plate to see if a sympathetic detonation in a neighboring explosive device with a reasonable stand off is possible. Note that a ramp wave such as seen in these experiments will accelerate the cover plate of the donor system in a manner similar to the acceleration of a projectile by a powder gun. Fig. 5 outlines a schematic for the TEXT VII experiment that has been assembled and waiting on testing. A thermal and hydrodynamic coupled code ALE 2D will be use to model the results of these and future experiments.

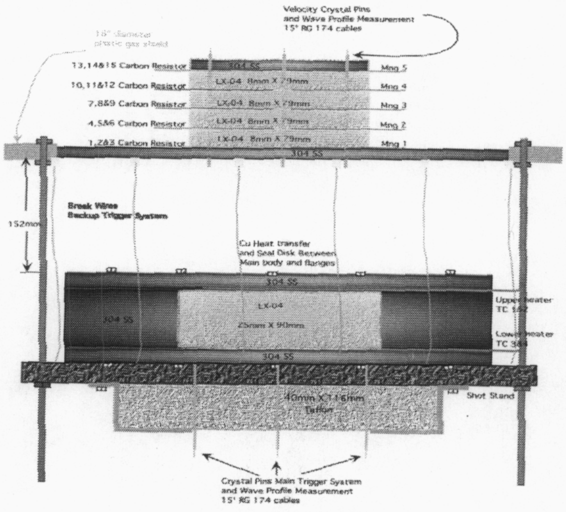

Figure 5. Schematic of TEXT VII thermal explosion experiment

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